High-precision self-tool CD matching with focus-target assist pattern by computational ways

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ABSTRACT

As design rules of advance devices shrink down, not only process-window budget of lithography process is getting tighter, but also CD control to target is more important especially for multiple tool process environment in HVM (High Volume Manufacturing). The tool induced CD bias or CD difference between tools are derived by minute amount of residual imaging parameters even though with strict control in system. The tool to tool CD mismatch is able to be reduced to nanometer or sub-nanometer scale for critical features of concern by using released tools such as LithoTuner PMFC™ (Pattern Matcher Full Chip). During the matching process, tunable imaging parameters such as pupil shape and stage tilt can be used as matching knobs. In this paper, CD mismatch due to film stack change on same exposure tool was studied to check feasibility of PMFC application. Also, CD variation and its impact on CD mismatch by focus error as amount of intrinsic system was investigated as well. By considering the focus impact on CD proximity bias via simple mathematical ways, the CD matching process could be more accurately performed and verified.

Keywords: Proximity CD bias, Tool to tool CD matching, Self-tool CD matching, PMFC, Best focus target

1. SELF-TOOL MATCHING AND PROCEDURE

During the process tuning stage before transferring to HVM, bigger proximity CD bias could be happened when one or several films among substrate/ BARC/ Resist/ ITC(Immersion Top Coat) films are changed for process improvement reason. One of effective solutions to compensate the change is making new OPC reticle, but it would take several months for doing new modeling, OPC tuning, and delivering of new mask for the new process. Litho Tuner PMFC was applied to solve such issued cases and its performance was compared.

1.1 Process condition

One of BEOL layer of L2x layer was investigated in this study since its film stack change gave bigger CD change than control spec. comparing to reference state. Illumination setting of reference layer was annular setting. ASML NXT19x0 tool was available for the process with FlexRay™ optics to use freeform source in the matching process. In the new state of TBM (To-Be-Matched) condition, the existing resist material with ITC was changed to specific resist without ITC.

Table.1 Process condition

Device node/ Layer	L2x / One of BEOL
Illumination setting of reference	Annular
Exposure tool	193nm , NXT19x0
Changed process in TBM	Thickness of ITC, Resist
Max CD mismatch before correction	~ 5nm

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1.2 Procedure for self-tool matching

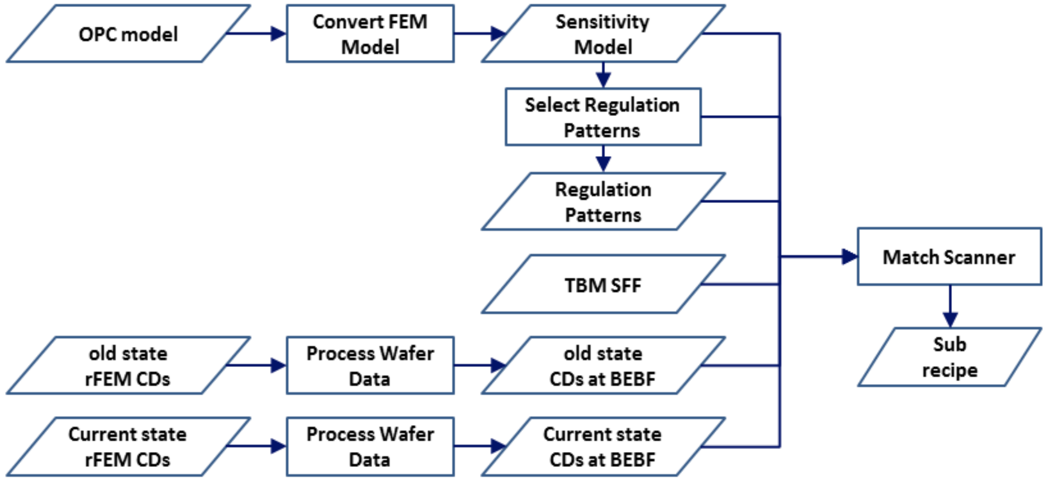


Fig.1 Work flow of BRION Litho Tuner Pattern Matcher Full chip for self-tool matching application

Fig. 1 illustrates major workflow of PMFC self-tool matching. Comparing to tool to tool CD matching it uses CD measurement data from reference scanner and TBM (To-Be-Matched) scanner, self-tool matching uses old and new state of CD measurement data. Old and new state refers to its different wafer film stack. Differences between tool to tool matching and self-tool matching are using old state of CD data as reference CD data and using new state of CD data as TBM CD data. Therefore, self-tool matching is driven by CD difference on the same scanner with different process condition.

Sensitivity model which predicts accurate CD changes upon tuning knobs is converted from OPC model that describe the lithography process including mask, optics, and resist of reference state. PMFC relies on the measured ΔCD and the simulated CD sensitivity to optical changes. Assuming resist processes have similar MEEF(Mask Error Enhancement Factor), The CD changes in resist is equal to the CD change in the aerial image multiplied with the resist MEEF. When two resist processes are both capable of imaging the same layer with the same illumination, their resist MEEF must be very similar. In that case, there is no need to perform separate modeling for the two resist.

Based on sensitivity model, converted from OPC model, regulation pattern can be selected among several thousand OPC calibration pattern pool. PMFC tool calculates knob sensitivities for all of critical pattern of concern and user-defined number of regulation pattern can be selected as order of the highest sensitivities to tuning knobs. Among the matching knobs, pupil shape and NA were used in this study.

Also SFF (Scanner Fingerprint File) can be used which contains source pupil measurement, lens aberration, MSD x/y/z (Moving Standard Deviation in x, y and z), and laser bandwidth.

1.3 Random FEM exposure

Random Focus Exposure Matrix (rFEM) is recommended during matching process to reduce wafer usage and measurement noise by Bossung fit. As part of PMFC, a number of preconfigured templates for random FEM jobs are provided, each covering a specific range of focus variation. These random FEM conditions are associated with scanner exposure job, The overall working flow is described as follows:

a) Determine the process focus range and best dose
b) Load the rFEM recipe template into scanner
c) Modify the condition setting field by field
d) Save the modified recipe and use it for exposure
e) Determine the image shift parameters according to the fixed field size
f) Set up the image shifts parameters on scanner for reticle

2. MATCHING

2.1 Moderate matching by free form pupil: Prediction and Verification

The first matching result by freeform source is shown in Fig.2 (Session A#93). There was a bigger CD mismatch around 5 nm in pre-matching due to mainly change of ITC/ resist. The first 10 features in x-axis of the plot mean critical features for CD measurement during lot operation. The rest of ones are critical through pitch pattern for monitoring of other pattern's behavior. In addition, 200 regulation patterns were also selected to monitor any bigger excursion of CD mismatch than allowed range (+/-5nm in Session A) as a mean to monitor full chip representative patterns by computational way. As seen in Fig.2, mismatching amount of pre matching was reduced to 1.63nm RMSE from 3.17nm (48.6%).

It was also verified on wafer as displayed by green line in the plot. Curvature trend of wafer data was matched to the predicted post matching curve. Furthermore, wafer result was better (1.06nm RMSE, 66.6% improvement) than the predicted performance.

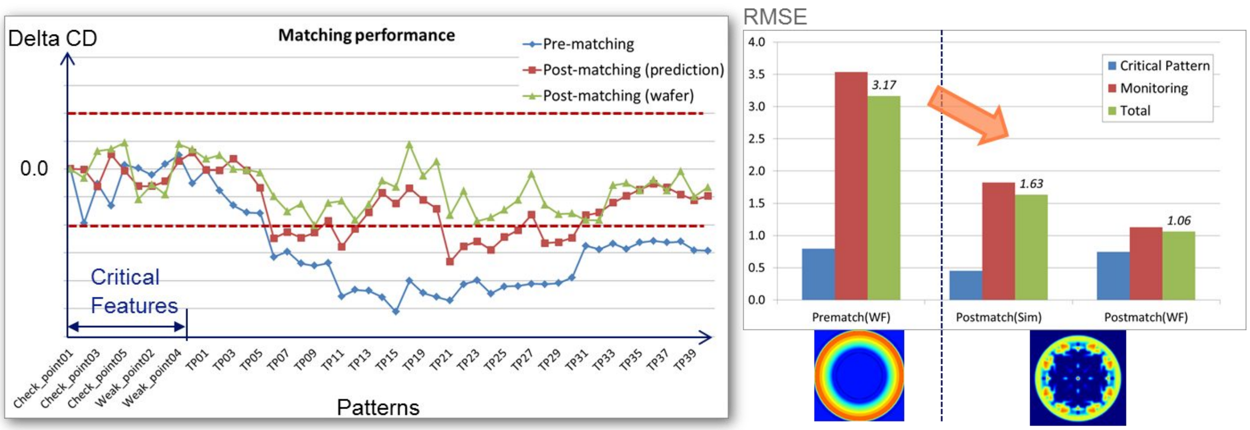


Fig.2 Predicted matching performance and wafer verification (Session A_#93)

2.2 Aggressive matching with more degree of freedom pupil: Prediction

PMFC provides further matching performance with more degree of freedom of pupil shape. The number of UIP(Uniformity Improvement Package)metric in table 3 implies the overlap integral between pre-matching and post-matching pupil. Fig.3 (a) is the matching session that focuses on critical pattern matching only (check patterns and through-pitch patterns) without giving any of constraints to regulation patterns, and to pupil shape. Most of critical features are quite well controlled and its CD mismatch in RMSE is 0.42nm (86.8% improvement). However, as seen on the bottom of Fig.3 (a), mismatch of regulation patterns goes bigger, so it could be risky of mismatch for the rest of unmonitored patterns in full chip layout. By controlling of the regulation pattern with constraint range, excursion of such behavior can be prevented as in Fig.3 (b). Anyhow, better matching performance was obtained even with more strict regulation control in session C comparing to session A since it used more degree of freedom pupil.

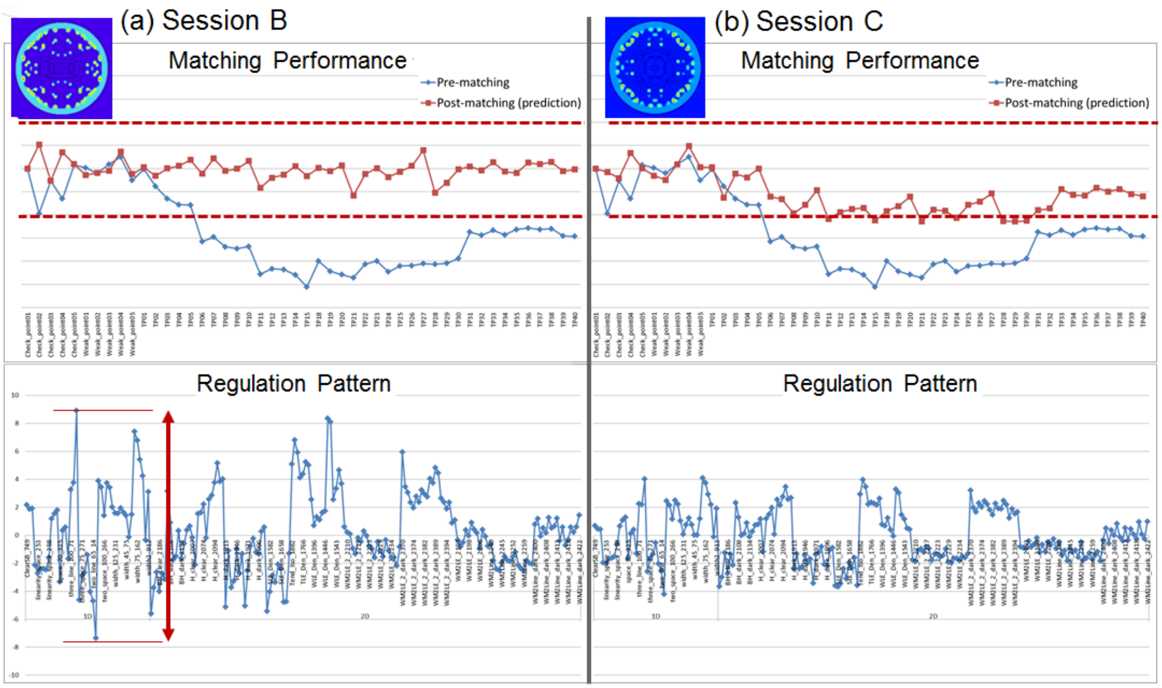
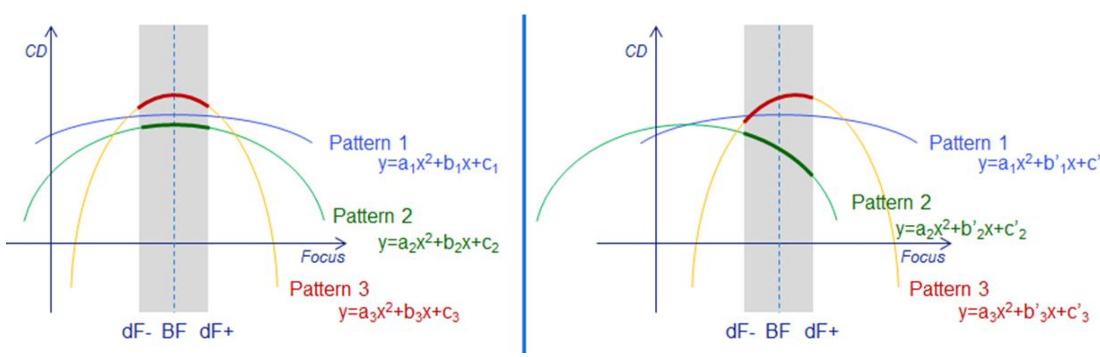


Fig.3 More aggressive CD matching with more degree of freeform in source shape

3. FOCUS TARGET

3.1 Selection of focus target: aware of systematic focus variation

Bossung curves as illustrated in Fig.4, minute change of focus during matching process could give non-negligible amount of CD change. Even though with strict control of focus on system, there is always few nanometers , or sometimes several ten nanometer variation could be made, tool to tool, chuck to chuck, and scan up and down movement when wafers are exposed. Since best focus locations of each patterns are different due to Mask3D impact, overall CD variation by systematic focus error can be dependent on each focus target pattern. Selection of focus target pattern is very important in such reason. The intuitive way to choose the most isolated feature among critical pattern is no more valid as seen in Fig.4 (b). In this study, focus target pattern was obtained by statistical ways considering of focus sensitivity and best focus location of 2nd order polynomial fitting curves as in Fig. 5 which were calculated from random FEM wafer data where systematic focus variation with +/- 10nm assumption. As summarized in Table 2, focus target pattern of preference can be listed. TP23 in the table was seemingly reasonable choice to minimize systematic focus driven CD change.



(a) Case of less best focus shift (b) Case of bigger best focus shift by M3D impact

Fig.4 Amount of CD variation by intrinsic stage focus variation

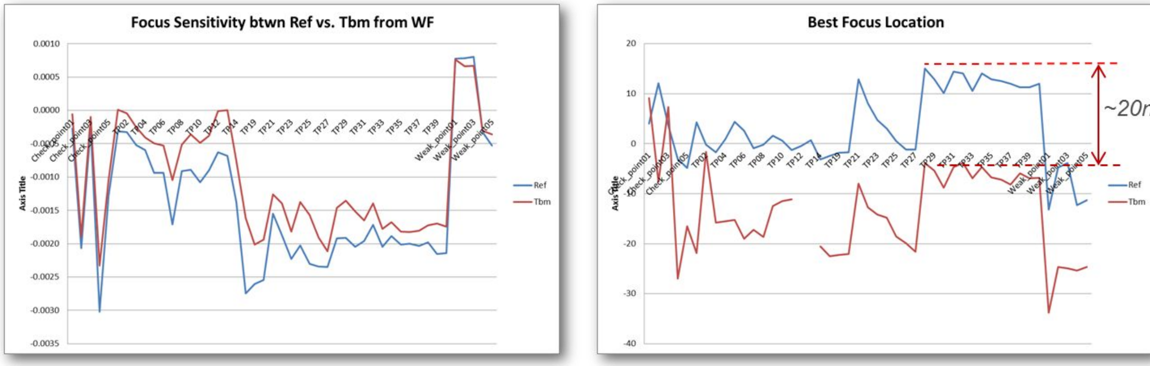


Fig.5 Focus sensitivity(a) and best focus location of each pattern (b)

Table.2 Result table to select focus target for matching process

(a) Result by reference wafer data

Rank	RMSE	Pattern
1	0.473	23_TP23
2	0.476	05_TP05
3	0.477	01_TP01
4	0.479	41_Check_point01
5	0.484	43_Check_point03
6	0.495	24_TP24
7	0.506	06_TP06
8	0.515	22_TP22
9	0.537	09_TP09
10	0.563	04_TP04

(b) Result by TBM wafer data

Rank	RMSE	Pattern
1	0.412	22_TP22
2	0.413	23_TP23
3	0.414	09_TP09
4	0.417	24_TP24
5	0.423	05_TP05
6	0.426	10_TP10
7	0.427	04_TP04
8	0.430	03_TP03
9	0.431	11_TP11
10	0.444	45_Check_point05

3.2 Potential impact on CD variation by systematic focus change

In Fig.6 CD variation of critical patterns by systematic focus change (assumed as +/-10nm) were calculated with respect to different focus target pattern. Check point5 in Fig.6 (a) is one of the isolated features and the CD change by focus variation is much bigger than that of TP23 as shown in Fig.6 (b). If the systematic focus variation impact to exposure process, CD varies not only during pre-matching/ post-matching, but also could impacts during verification exposure as well.

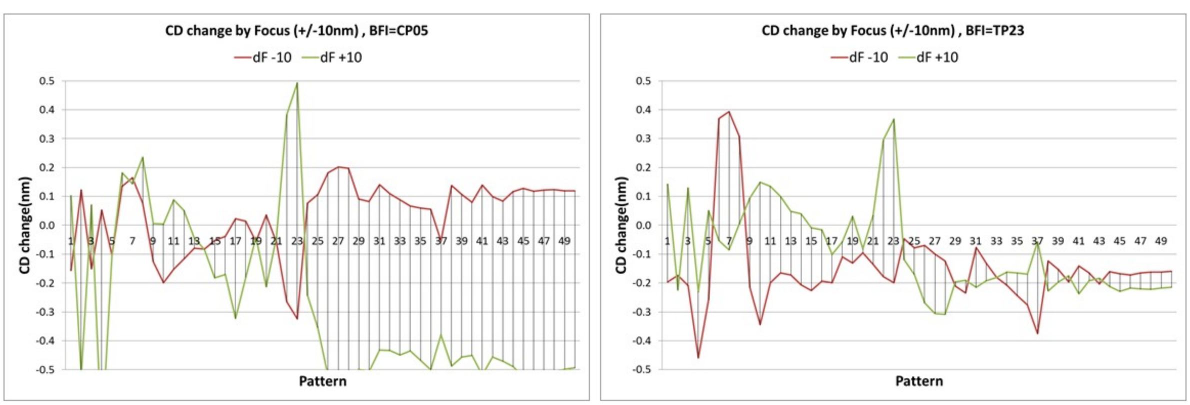


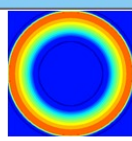
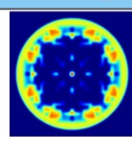
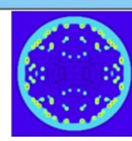
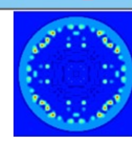
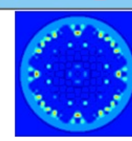
Fig.6 CD variation by different focus target pattern with systematic focus variation (in the assumed range)

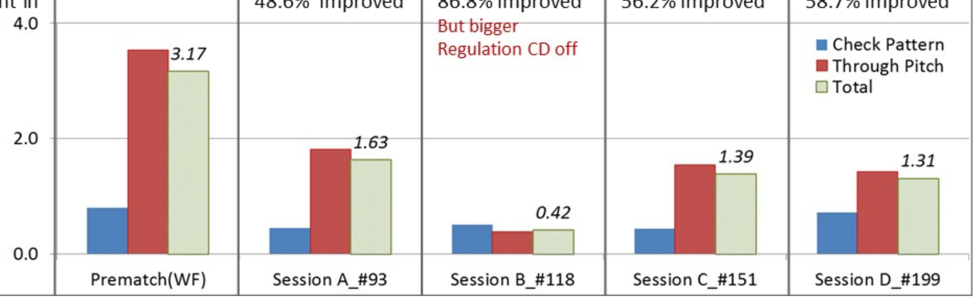
4. MATCHING SUMMARY

4.1 CD matching result

All the matching session and results are summarized in Table 3. Matching with freeform source with moderate modulation of pupil shows comparable result (Session A). More degree of freedom source can be enabled by UIP (Uniformity Improvement Package) exceed function in PMFC and matching performance for targeted feature was maximized without regulation constraints (Session B). In practical case, bigger deviation of imaging performance for rest of pattern is not allowed, so, reasonable range of regulation pattern is required especially for more aggressive freeform pupil matching (Session C, D). Self-tool CD matching was performed with new focus target pattern TP23 and the session result was summarized in column session D on Table 3. The rest of matching conditions like regulation range and feature specific weight factors were kept same as session B and C. Comparing to session C , the simulation result of session D with new focus target showed slightly better performance. The reason of improvement is seemingly due to relatively less uncertainty of CD variation by systematic focus change during reference and to-be-matched exposure.

Table.3 Summary of matching session

	Pre matching	Session A_#93	Session B_#118	Session C_ #151	Session D_ #199
IL source					
NA	-	-0.031	0.000	-0.002	-0.002
UIP exceed	-	No	Yes	Yes	Yes
UIP metric	-	0.821	0.656	0.686	Not checked
Weight		Weighted	-	Weighted	Weighted
Regulation		±5.0	±10000	±3.5	±3.5
Focus Target	-	CP02 for TBM CP04 for Ref	CP02 for TBM CP04 for Ref	CP02 for TBM CP04 for Ref	TP23 for TBM TP23 for Ref
Improvement in RMSE (Sim)		48.6% improved	86.8% improved But bigger Regulation CD off	56.2% improved	58.7% improved



4.2 CD matching impact on process window

After application of each matching recipe, process windows for each matching conditions were simulated as illustrated in Fig. 7. Common process window of all critical patterns were simulated with +/- 1% spec. Comparing with pre-matching state, common process windows were not degraded, rather, they were slightly improved. The reason of improvement comes from adjustment of target CD by PMFC after CD matching. There was no degradation of imaging quality by matching process.

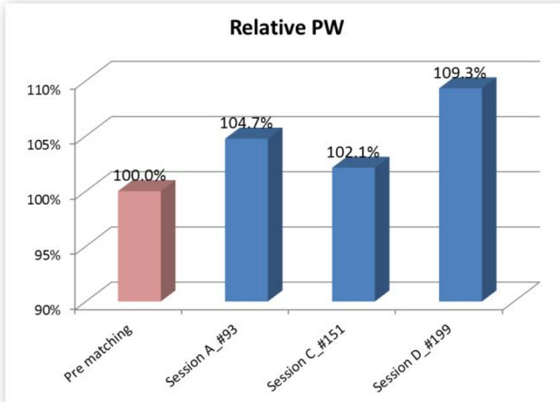


Fig.7 CD matching impact on process window : Relative values of simulated PW(Process Window) area

5. CONCLUSION

Feasibility test of self-tool matching was performed and verified on wafer when some of process film stacks are changed. Further matching cases to improve matching performance for limited critical patterns were performed with more degree of freedom source and with and without regulation pattern restriction. Computational and statistical approach to select focus target pattern (as Best Focus Indicator) was investigated with analysis of random FEM exposure. The choice of proper focus target pattern allows minimization of CD variation by systematic focus variation during pre-matching/post-matching and verification exposure that could come from intrinsic performance of chuck and leveling, chuck to chuck, scan-up & down, and tool-tool difference.

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